PROLOG

Tests, Backtracking, and Recursion

Artificial Intelligence Programming in Prolog

Lecture 3

30/09/04

Re-cap

- A Prolog program consists of predicate definitions.
- A predicate denotes a property or relationship between objects.
- Definitions consist of clauses.
- A clause has a head and a body (Rule) or just a head (Fact).
- A head consists of a predicate name and arguments.
- A clause body consists of a conjunction of terms.
- Terms can be constants, variables, or compound terms.
- We can set our program goals by typing a command that unifies with a clause head.
- A goal unifies with clause heads in order (top down).
- Unification leads to the instantiation of variables to values.
- If any variables in the initial goal become instantiated this is reported back to the user.

Correction: Re-trying Goals

- When a question is asked with a variable as an argument (e.g. `greet(Anybody).`) we can ask the Prolog interpreter for multiple answers using: `;`

```
greet(hamish):- write('How are you doin, pal?').
greet(amelia):- write('Awfully nice to see you!').
```

```
| ?- greet(Anybody).
       How are you doin, pal?
       Anybody = hamish? ;
       Awfully nice to see you!
       Anybody = amelia? ;
       no
```

- `;` fails the last clause used and searches down the program for another that matches.
- It then performs all the tasks contained within the body of the new clause and returns the new value of the variable.

Tests

- When we ask Prolog a question we are asking for the interpreter to prove that the statement is true.

```
?- 5 < 7, integer(bob).
```

`yes` = the statement can be proven.

`no` = the proof failed because either
  - the statement does not hold, or
  - the program is broken.

`Error` = there is a problem with the question or program.

nothing = the program is in an infinite loop.

- We can ask about:
  - Properties of the database: `mother(jane,alan).`
  - Built-in properties of individual objects: `integer(bob).`
  - Absolute relationships between objects:
    - Unification: =/2
    - Arithmetic relationships: <, >, =<, >=, =:=, +, -, *, /

PROLOG

Arithmetic Operators

- Operators for arithmetic and value comparisons are built-in to Prolog

  = always accessible / don't need to be written

- Comparisons: <, >, =<, >=, =:= (equals), =\= (not equals)

  = Infix operators: go between two terms.

  `=</2` is used

  - `5 =< 7.` (infix)
  - `=<(5,7).` (prefix) ← all infix operators can also be prefixed

- Equality is different from unification

  =/2 checks if two terms unify

  =:=/2 compares the arithmetic value of two expressions

```
?- X=Y.     ?- X=:=Y.              ?-X=4,Y=3, X+2 =:= Y+3.
yes         Instantiation error     X=4, Y=3? yes
```

Arithmetic Operators (2)

- Arithmetic Operators: +, -, *, /
  = Infix operators but can also be used as prefix.
  – Need to use `is/2` to access result of the arithmetic expression otherwise it is treated as a term:

```
|?- X = 5+4.
X = 5+4 ?
yes
(Can X unify with 5+4?)
```

```
|?- X is 5+4.
X = 9 ?
yes
(What is the result of 5+4?)
```

- Mathematical precedence is preserved: /, *, before +,-
- Can make compound sums using round brackets
  – Impose new precedence
  – Inner-most brackets first

```
| ?- X is (5+4)*2.
X = 18 ?
yes
```

Tests within clauses

- These operators can be used within the body of a clause:
  - To manipulate values,

```
sum(X,Y,Sum):-
   Sum is X+Y.
```

  - To distinguish between clauses of a predicate definition

```
bigger(N,M):-
   N < M, write('The bigger number is '), write(M).
bigger(N,M):-
   N > M, write('The bigger number is '), write(N).
bigger(N,M):-
   N =:= M, write('Numbers are the same').
```

Backtracking

```
|?- bigger(5,4).

    bigger(N,M):-
        N < M,
        write('The bigger number is '), write(M).
    bigger(N,M):-
        N > M,
        write('The bigger number is '), write(N).
    bigger(N,M):-
        N =:= M,
        write('Numbers are the same').
```

Backtracking

```
|?- bigger(5,4).

    bigger(5,4):-
        5 < 4,      ← fails         Backtrack
        write('The bigger number is '), write(M).
    bigger(N,M):-
        N > M,
        write('The bigger number is '), write(N).
    bigger(N,M):-
        N =:= M,
        write('Numbers are the same').
```

Backtracking

```
|?- bigger(5,4).

    bigger(N,M):-
        N < M,
        write('The bigger number is '), write(M).
    bigger(5,4):-
        5 > 4,
        write('The bigger number is '), write(N).
    bigger(N,M):-
        N =:= M,
        write('Numbers are the same').
```

Backtracking

```
|?- bigger(5,4).

    bigger(N,M):-
        N < M,
        write('The bigger number is '), write(M).
    bigger(5,4):-
        5 > 4,
        write('The bigger number is '), write(5).
```

← succeeds, go on with body.

Reaches full-stop
= clause succeeds

```
The bigger number is 5
yes
|?-
```

Backtracking

```
|?- bigger(5,5).
```
← If our query only matches the final clause

```
    bigger(N,M):-
         N < M,
         write('The bigger number is '), write(M).
    bigger(N,M):-
         N > M,
         write('The bigger number is '), write(N).
    bigger(5,5):-
         5 =:= 5,
         write('Numbers are the same').
```
← Is already known as the first two clauses failed.

Backtracking

```
|?- bigger(5,5).
```
← If our query only matches the final clause

```
bigger(N,M):-
     N < M,
     write('The bigger number is '), write(M).
bigger(N,M):-
     N > M,
     write('The bigger number is '), write(N).
bigger(5,5):-
```
← Satisfies the same conditions.

```
     write('Numbers are the same').
```

```
Numbers are the same
yes
```

Clauses should be ordered according to specificity
Most specific at top ⟷ Universally applicable at bottom

Reporting Answers

`|?- bigger(5,4).`	← Question is asked
`The bigger number is 5`	← Answer is written to terminal
`yes`	← Succeeds but answer is lost

- This is fine for checking what the code is doing but not for using the proof.

```
|?- bigger(6,4), bigger(Answer,5).
Instantiation error!
```

- To report back answers we need to
  - put an uninstantiated variable in the query,
  - instantiate the answer to that variable when the query succeeds,
  - pass the variable all the way back to the query.

Passing Back Answers

- To report back answers we need to
  1. put an uninstantiated variable in the query,

```
| ?- bigger(6,4,Answer),bigger(Answer,5,New_answer).

    bigger(X,Y,Answer):- X>Y, Answer = X.
    bigger(X,Y,Answer):- X=<Y, Answer = Y.
```

  2. instantiate the answer to that variable when the query succeeds,
  3. pass the variable all the way back to the query.

Head Unification

- To report back answers we need to
    1. put an uninstantiated variable in the query,

```
| ?- bigger(6,4,Answer),bigger(Answer,5,New_answer).
```

1 2 3

```
bigger(X,Y,X):- X>Y.
bigger(X,Y,Y):- X=<Y.
```

Or, do steps 2 and 3 in one step by naming the variable in the head of the clause the same as the correct answer.

= head unification

Satisfying Subgoals

- Most rules contain calls to other predicates in their body. These are known as Subgoals.
- These subgoals can match:
  - facts,
  - other rules, or
  - the same rule = a recursive call

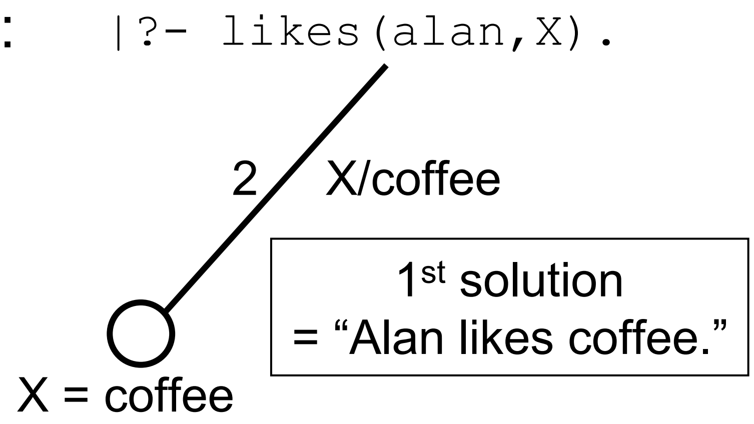
```
1) drinks(alan,beer).
2) likes(alan,coffee).
3) likes(heather,coffee).

4) likes(Person,Drink):-
        drinks(Person,Drink).    ← a different subgoal
5) likes(Person,Somebody):-
        likes(Person,Drink),     ← recursive subgoals
        likes(Somebody,Drink).   ←
```

Representing Proof using Trees

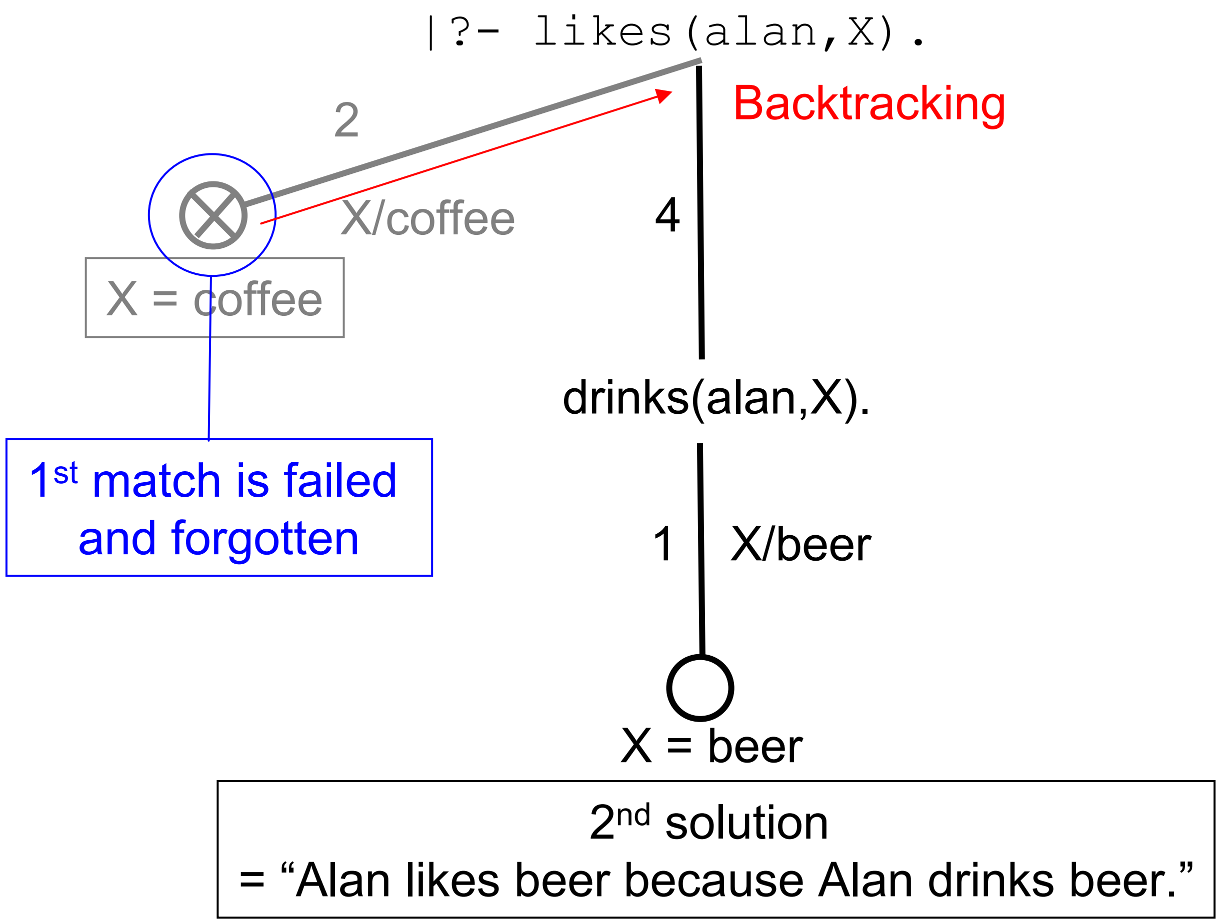
- To help us understand Prolog's proof strategy we can represent its behaviour using AND/OR trees.

1. Query is the top-most point (node) of the tree.
2. Tree grows downwards (looks more like roots!).
3. Each branch denotes a subgoal.
   1. The branch is labelled with the number of the matching clause and
   2. any variables instantiated when matching the clause head.
4. Each branch ends with either:
   1. A successful match ○ ,
   2. A failed match ⊗, or
   3. Another subgoal.



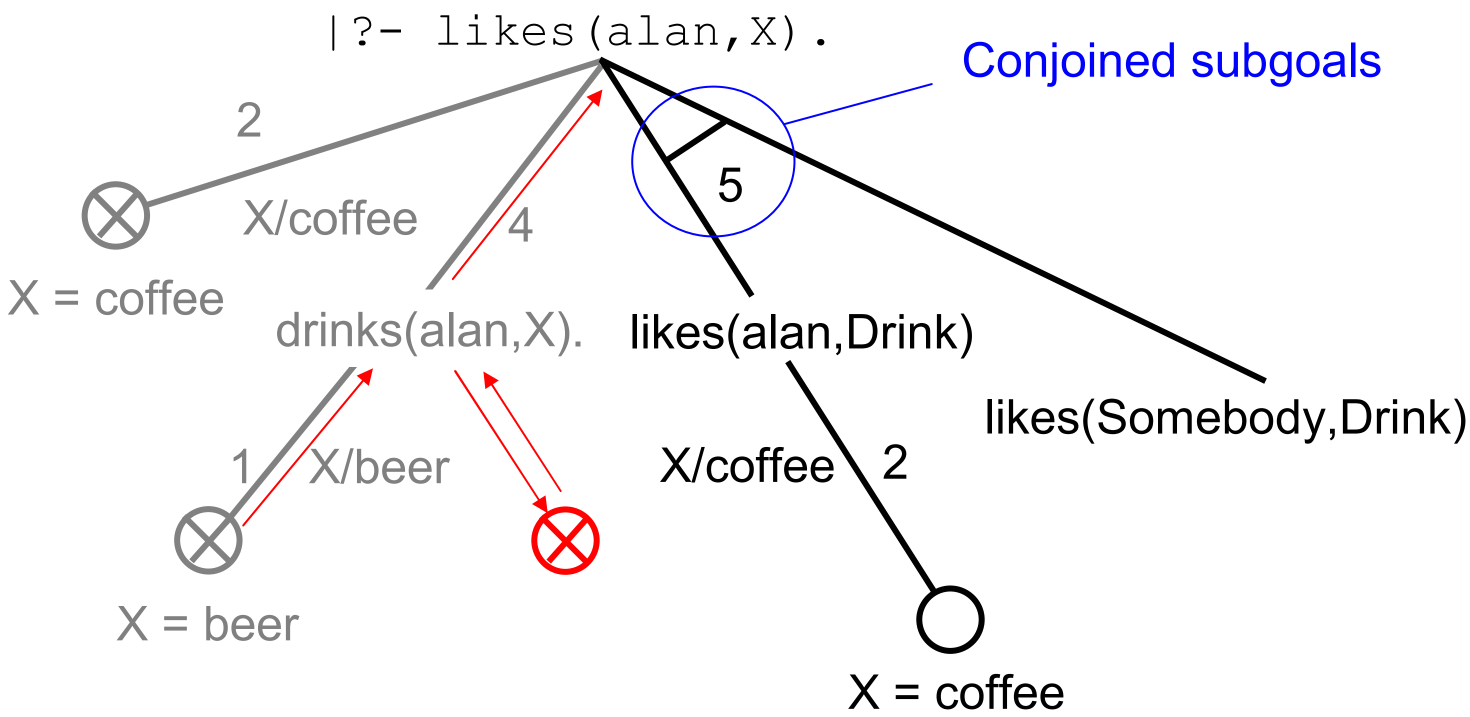
Representing Proof using Trees (2)

- Using the tree we can see what happens when we ask for another match (;)



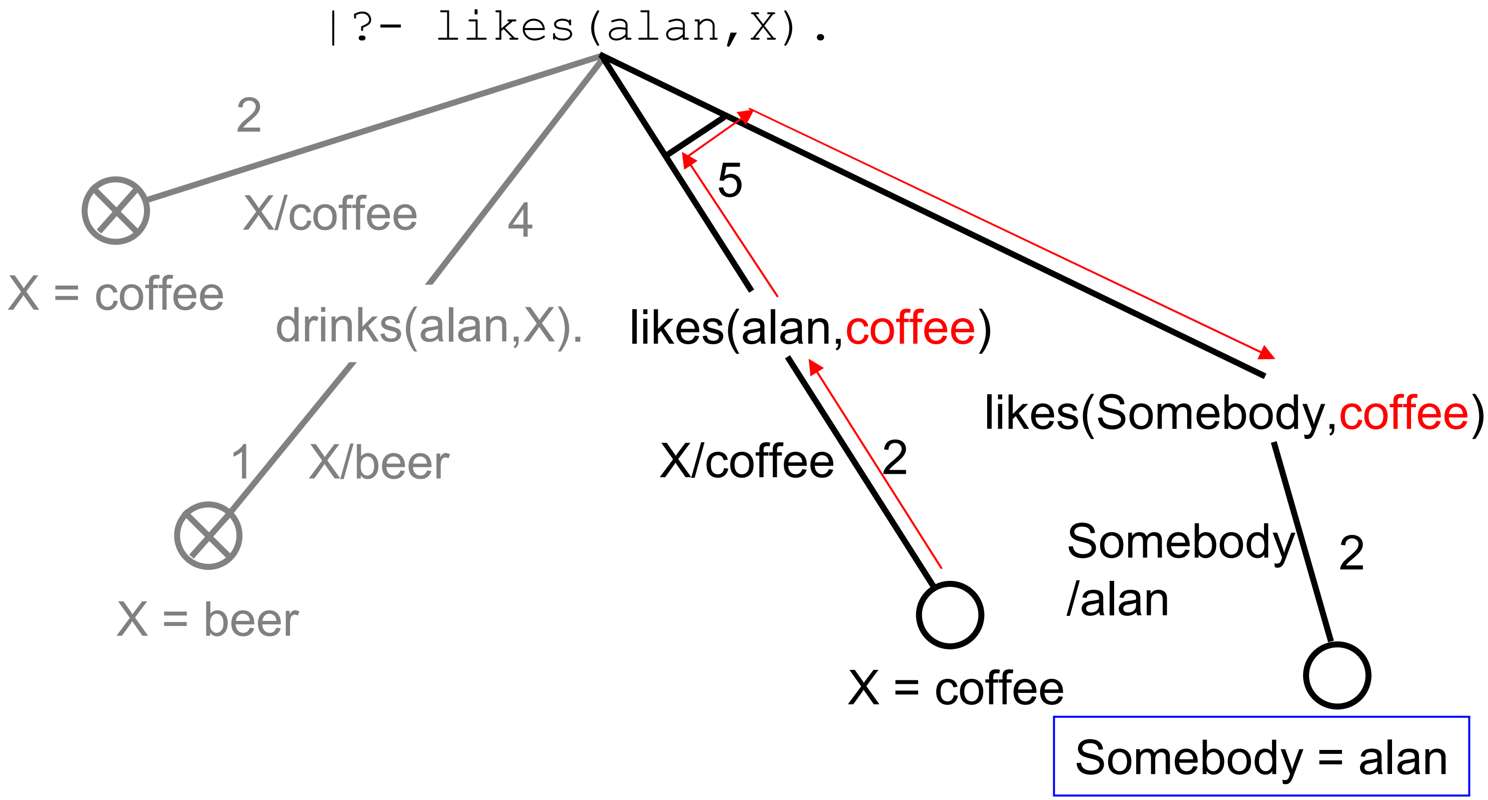
Recursion using Trees

- When a predicate calls itself within its body we say the clause is recursing



Recursion using Trees (2)

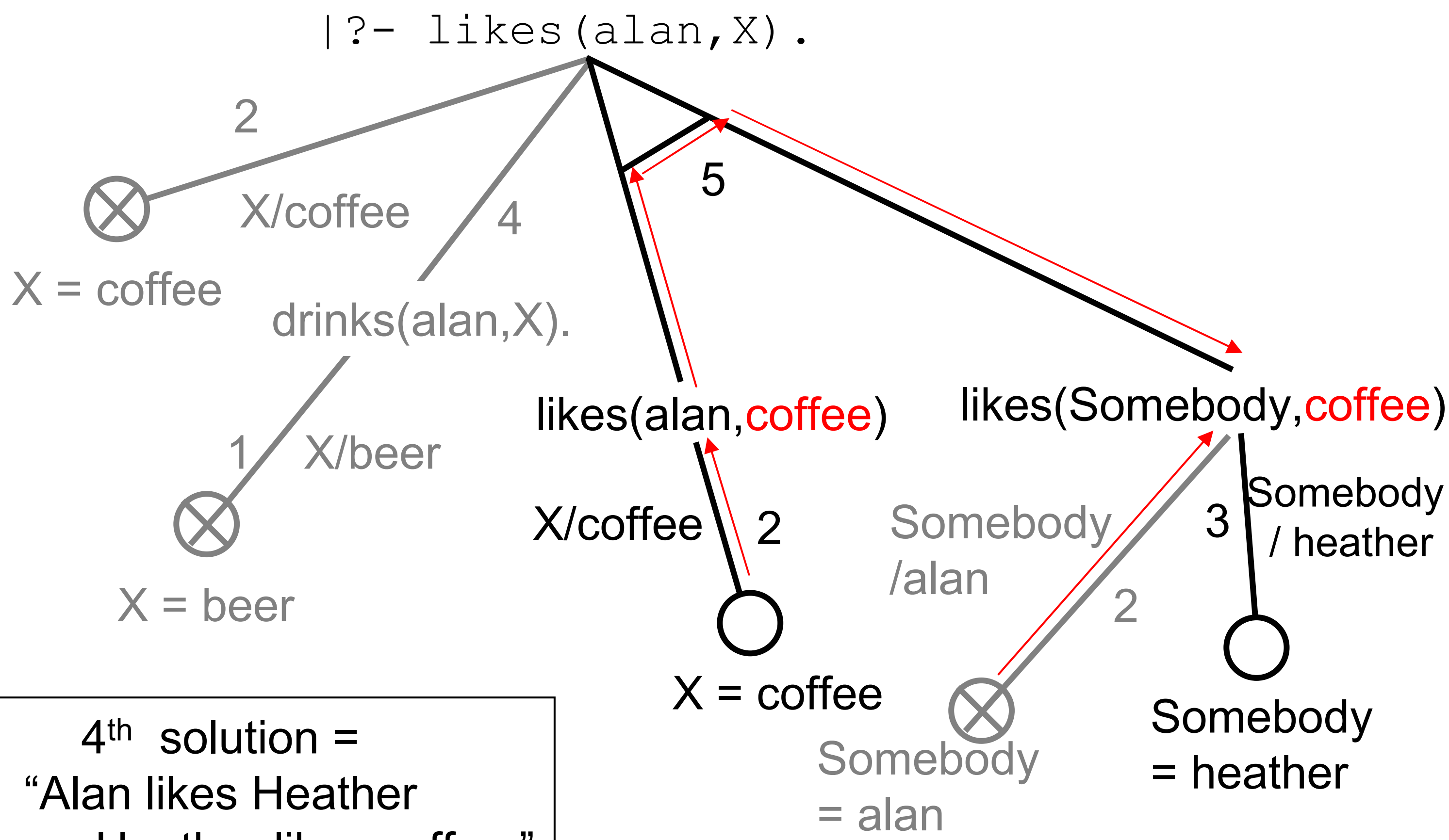
- When a predicate calls itself within its body we say the clause is recursing



3rd solution = "Alan likes Alan because Alan likes coffee."

Recursion using Trees (3)

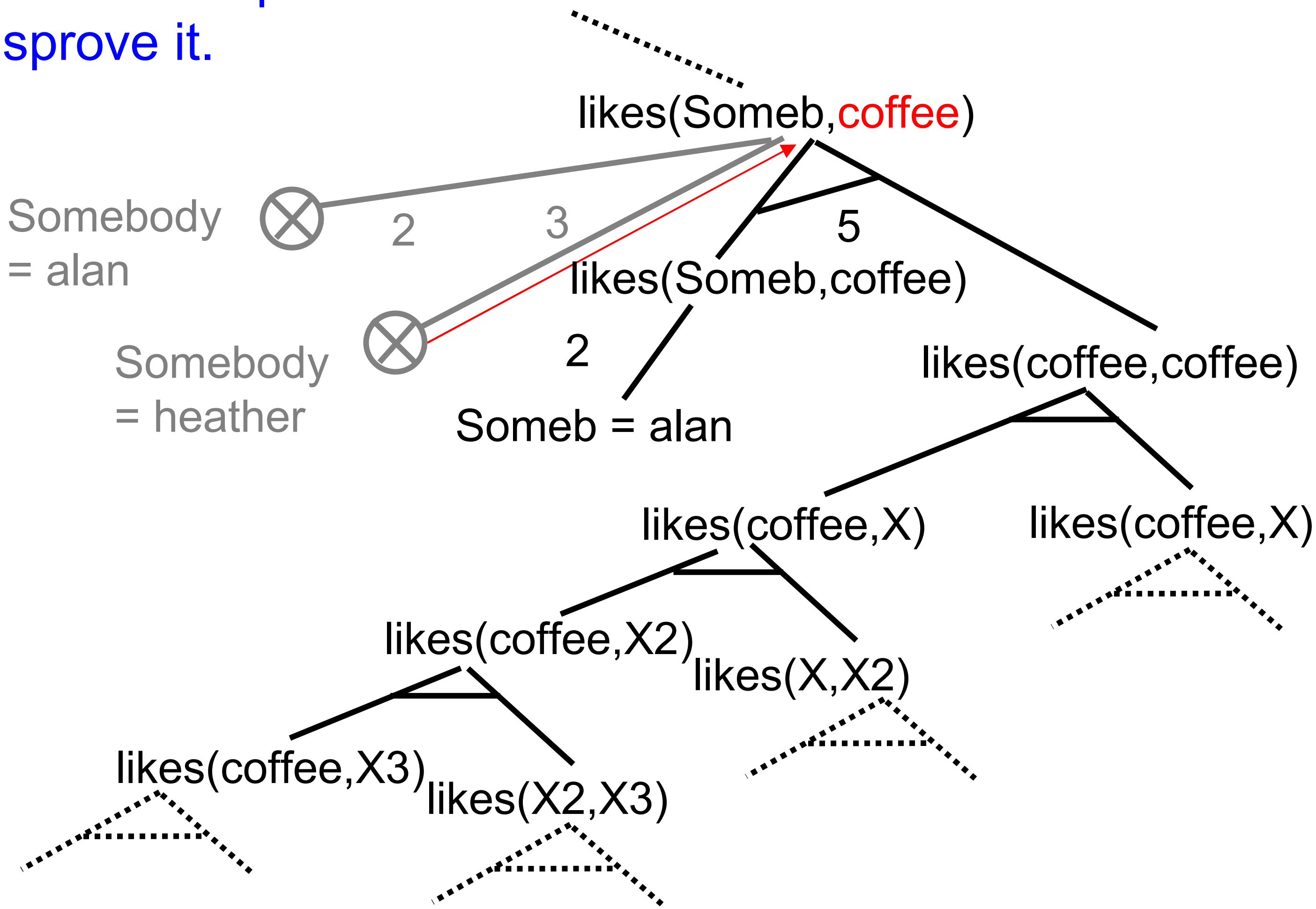
- When a predicate calls itself within its body we say the clause is recursing



4th solution =
"Alan likes Heather
because Heather likes coffee."

Infitite Recursive Loop

- If a recursive clause is called with an incorrect goal it will loop as it can neither prove it nor disprove it.



PROLOG

The central ideas of Prolog

- SUCCESS/FAILURE
  - any computation can "**succeed**" or "**fail**", and this is used as a '**test**' mechanism.
- MATCHING
  - any two data items can be compared for similarity, and values can be bound to variables in order to allow a match to succeed.
- SEARCHING
  - the whole activity of the Prolog system is to search through various options to find a combination that succeeds.
    - Main search tools are backtracking and recursion
- BACKTRACKING
  - when the system fails during its search, it returns to previous choices to see if making a different choice would allow success.